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MAY 78 D SHARIR, H PORTNOY, J ROM DA-ERO-78-G-21

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A Study of the Effects of Jets Injected from a Slender Body of Revolution on the Side Forces Acting on it at Large Angles of Attack in Low Speeds

by

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A STUDY OF THE EFFECTS OF JETS INJECTED FROM A SLENDER BODY OF REVOLUTION ON THE SIDE FORCES ACTING ON IT AT LARGE ANGLES OF ATTACK IN LOW SPEEDS.

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CONTENTS

ABSTRACT

The side forces and moments that appear on slender bodies at high angles of attack can be affected by transition inducing devices installed on the nose of the body. In the present investigation the use of air jets as active devices for affecting these forces is studied. It is found that symmetrical injection of subsonic jets near the nose of the body can reduce the side force and can even change its direction. It is found that for the present test conditions - i.e. subsonic flow at subcritical Reynolds numbers a very small amount of injection is sufficient to affect the induced lateral forces and moments.

NOMENCLATURE

N_{oR}	normal force
Y	side force
n	yawing moment
C_{nor}	normal force coefficient $C_{nor} = \frac{N_{oR}}{qA}$
C_Y	side force coefficient $C_Y = \frac{Y}{qA}$
C_{Ym}	maximum side force coefficient
C_n	yawing moment coefficient
C_m	pitching moment coefficient
q	dynamic pressure $q = \frac{\rho_\infty V^2}{2}$
ρ_∞	freestream density
A	cross sectional area of the model = $0.44 \times 10^{-2} m^2$
D	diameter of cylinder 0.075m
Re_D	Reynolds number based on diameter
Re_C	cross-flow Reynolds number $Re_C = Re_D \sin\alpha$
C_μ	blowing coefficient defined as $C\mu = \dot{m}_j V_j / \frac{1}{2} \rho_\infty V^2 A$
$\dot{m}_j$	nozzle mass flow rate
V_j	theoretical jet velocity (assuming fully expanded isentropic flow)
V	velocity of free stream
M	Mach number of free stream
α	angle of attack
α_o	onset angle for side forces
β	sideslip angle

INTRODUCTION

The occurrence of asymmetric vortex flow and hence side forces and yawing moments on bodies of revolution at high angles-of-attack and zero sideslip has been observed experimentally and is under intensive studies at various laboratories.

All previous investigations have shown that the nose shape is one of the most significant parameters affecting side force characteristics. It has been found experimentally that it is possible to reduce side forces by the use of devices causing boundary layer transition or vortex generators on the nose.

In the present investigation air jets blown from a body of revolution are used in order to reduce the side forces.

There are many parameters that may affect these side forces such as the position of the stations on the body for these jets, the polar angle at each station, the mass flow and velocities of the jets. Some of these parameters have been investigated and reported in this paper.

At moderate angles of attack the adverse cross-flow pressure gradient on the leeside of the body causes the boundary layer to separate and then to roll-up into a system of distinct vortices.

The rolled-up vortex sheet may stay joined to the body and be continuously fed from the separated boundary layer or it may leave the body entirely further downstream. Since the boundary layer separation is caused by the adverse pressure gradient, the separation line may be expected to be close to the line of the minimum pressure coefficient on the leeward side of the body [1].

Due to geometrical irregularities of the nose of the body or irregularities in the flow direction one side of the boundary layer may separate first from the body, retaining a certain vortex strength in the corresponding rolled-up vortex sheet. The other side of the boundary layer may remain attached and separate only further downstream on the body with a correspondingly stronger vortex. Thus we find an asymmetric vortex system generated behind the body at high angles of attack. This is supported by the results of Ref. 2 where it is shown that the side forces are connected to asymmetry of circumferential pressure distribution and asymmetry of vortex sheet separation on the leeside of the body. In the visualization tests of Ref. 1 it is shown that as the angle of incidence increases the separation line is shifted towards the windward side. The circumferential angles of separation (ϕ_{s1}, ϕ_{s2}) as measured from the windward meridian, indicated a non-symmetrical separation on the cylindrical afterbody when laminar boundary layer conditions exist. This asymmetry increased with increasing angle of attack. The maximum angular difference very nearly coincided with the maximum measured side force. (The maximum angular difference was of the order of 20° to 40° for the sharp and slightly blunted slender noses respectively, while this difference decreased to 5° to 10° for the lowest fineness ratio nose).

At high angles of attack the side vortices could grow and separate at several points along the body: this phenomenon was found by [1], [2] and [3].

The phenomenon of these lateral forces can be also modeled by the impulsively started cross-flow analogy. The calculation of side forces

and pressure distributions on inclined cylindrical bodies at high angles of attack is presented by Lamont and Hunt in Ref. 4 and 5. Using the cross-flow analogy the induced lateral flow field is evaluated without specific reference to the state of the boundary layer on the body. The validity of this assumption must be studied.

The generally accepted results of the investigations of the phenomena associated with vortex asymmetry on slender bodies at high angles of attack are the following:-

(1) The initial direction of the side force is unpredictable because of its connection with small irregularities in the nose geometry; however once the direction is established this does not change as the incidence angle is increased.

(2) Reynolds number has no effect on the angle of onset of asymmetry but does have an effect on the magnitude of the side force. (The Reynolds number effect is in defining the boundary layer in the sense of whether it is supercritical or subcritical. For instance in Ref. 4 the relation of C_{Ym} in the supercritical to the subcritical is $1.5/_{2.5}$.).

(3) The magnitude of the side forces increases with increasing the finess ratio of the nose.

(4) Side forces remain small below $\alpha = 25°$. Beyond this they increase and reach peaks at around 35° - 40°, depending on the Mach number and geometrical configuration.

(5) The magnitude of the side force is decreased by as much as 80% when a boundary layer strip is installed on the windward side. This is a result of early transition to turbulent boundary layer.

Side forces and moments may be potentially hazardous to the control and stability of slender configurations such as fighters and modern missiles, at high angles of attack. These side forces and moments may be overcome by sufficient control authority and autopilot gain margin so that flight control is maintained, or by aerodynamic devices to suppress the asymmetric vortex pattern.

In Ref. (6), (7) and (8) the investigators have pointed out that the nose shape is a most significant parameter affecting side forces, therefore adding transition strips or vortex generators on the nose can reduce the side forces.

These devices cause regular symmetric boundary layer flow on the nose of the body, thus eliminating the previously discussed asymmetric boundary-layer separation and so the associated vortex system is symmetric, therefore, eliminating the large side forces and moments.

In the work of Keener and Chapman [6] reduction of side forces is achieved by adding meridianal strips of grit at the angular position $\theta = \pm 30°$. In Ref [7], the positioning of a ring on the nose caused a great reduction in the large yawing moments at high angles of attack. In the work of Clark, Peoples and Briggs [8] the addition of vortex generators at the nose was sufficient to cause the separated vortices to be more symmetrical at the critical angles of incidence. In this present investigation air jets blown from the body of revolution are used to affect flow symmetry and reduce the side forces and moments. This is shown by an experimental investigation wherein the side forces and moments are measured with the air jets blown at different blowing coefficients, C_μ.

Preliminary tests have been carried out in the high subsonic and the transonic flow regions. The results of these tests appear in Appendix A of this report.

II. TESTS

The experiments described herein were conducted in the Subsonic Wind Tunnel of the Aeronautical Research Center of the Technion with a cross section of 1m x 1m.

The model shown in Fig. 1 is an axisymmetric body of revolution with a body diameter of 3 in. and an overall finess ratio of 6.

Three different forebodies could be used; a pointed cone, a blunt cone and a blunt ogive (shown in Fig. 1).

After conducting some preliminary tests it was decided to blow jets from two stations, one very close to the nose apex and the second further along the nose (Fig. 1). At each station three pairs of holes were drilled at ±60° and ±30° as indicated, in Fig. 1 and the diameter of the injection holes was 1.2 mm perpendicular to the body's axis (this diameter was chosen so as to obtain blowing velocities of the same order of magnitude as the tunnel flow speed).

A system of rigid and flexible tubing was arranged in the model so as to obtain symmetrical blowing of the jets through a different pair of holes each time.

Throughout the experimental program, a six component internal strain gage balance was used to measure the aerodynamic forces and moments. This balance was very sensitive to side forces.

The experimental system is capable of changing the rate of flow and of providing measurements of the pressures and of the rates of flow.

The experiments were conducted at a flow speed of 20 m/sec (for a Reynolds number of 1.08×10^5 based on the diameter) with the pointed

cone configuration and for a range of angles of attack of 30° - 56°. In the preliminary tests we found this configuration to give the highest value of side force.

Tests with no injection and a few tests with injection were repeated in order to verify the repeatability of the test results. The jets were also blown without flow and the measured side force was found to be negligible, showing that the blowing is symmetrical.

Qualitative tests for flow visualization were also performed. Using oil paints on the model, the development of the stream lines on the body was followed. The flow patterns indicated positions of separation as shown in Fig. 2.

III. RESULTS

The results of the tests can be summarized according to the angular position of the jets on the model:

Blowing at 60° At both stations increased values of the side force coefficients in comparison to those obtained without blowing were observed.

Blowing at + 30° At station II, high values of side force coefficients were observed with increasing rate of flow. At station I, two interesting results were observed (see Fig. 3) - the line of $C_\mu = 166.33 \times 10^{-5}$, where the jets kept the side force coefficient from growing until 40° and then caused a peak higher than the original; and the experiments for $C_\mu = 289.34 \times 10^{-5}$, in which the side force coefficient followed the original line to an angle of 40° where there was a change of sign until a negative peak was reached at 44°, followed by a rise to a peak similar to the original.

Blowing at - 30° At station II, a reduction of the maximum side force coefficient of up to 50° was observed in the two experiments shown in Fig. 4.

Both the curves $C_\mu = 33.25 \times 10^{-5}$ and 285.7×10^{-5} decrease from their maxima at $\alpha = 46°$ to zero side force coefficient at $\alpha = 53°$.

The yawing moment coefficient was decreased in these experiments by up to 30%.

At station I, a meaningful reduction of side force for certain

angles of attack was observed (Fig. 5).

On the yawing moment coefficient curve (Fig. 6) we observed a meaningful reduction with jets blowing compared to the original curve.

On examination of the side force coefficient versus the rate of flow diagram (Fig. 7) it is obvious that there is an optimum rate of flow for blowing the jets. The arrows on the Figure point to a concentration of many test results (on this curve the side force direction is opposite to its direction on Fig. 5).

Side Forces Versus Reynolds Number

The experiments of this investigation were conducted in a range of Reynolds number from 1.07×10^5 to 1.69×10^5, based on the body's diameter.

Fig. 8 shows the change of side force coefficient versus cross-flow Reynolds number, at $C_\mu = 21.6 \times 10^{-5}$.

Consistency of Results

Fig. 9, which describes the experiments without blowing, shows good consistency up to 48°. From this point scattering of results can be observed but they are still acceptable as consistent (the scattering of results is a characteristic phenomenon in all works on this subject). It is common practice to attribute this to the fact that the side forces are sensitive to changes in the nose alignment and in the experimental conditions and also to mounting induced vibrations.

In the blowing experiments which were repeated, similar amplitudes were observed but the sign of the side force changed in some cases.

From the experiment that was conducted without flow it was found that no side forces were measured by the balance and the conclusion is that the blowing during the experiments was symmetrical.

Analysis of Oil Flow Photographs

From a comparison of the pictures with no blowing to those with blowing, which was carried out for two angles of attack, $\alpha = 46°$ and $\alpha = 48°$ (on which the maximum no blowing side force coefficient was observed), the following conclusions can be derived:

(1) The blowing of the jets delays the separation point to much further downstream on the body (because of the transition to turbulent flow).

(2) The flow separation lines on each side become more symmetrical.

These results are similar to the results described in Refs. 4,5, and 6, in which the investigators added rigid elements on the nose.

IV. DISCUSSION

From the results of this research it can be seen that it is possible to reduce side forces and even change their sign by blowing symmetric jets from the body as close as possible to the nose apex (the importance is, of course, in reducing the maximum side forces).

The most effective results appear on blowing at an angle of $-30°$ (on the windward side). It can be seen that the jet blowing is inefficient at angles of attack above 52°.

The amount of blowing used did not cause any change in the normal force and drag.

The rate of flow of the jets needed to reduce the side forces is very small. The solution is not sensitive to changes in the rate of flow; increasing the rate of flow did not cause significant changes in side force coefficient.

Effect of Angle of Attack - Increasing angle of attack causes the side force to increase until it reaches a peak at about 50°. Above this angle further increase of angle of attack causes decrease of the side forces.

Angle of Onset Asymmetry - From the results of the experiments it is clear that the blowing jets do not cause any change in the value of the angle of onset of asymmetry.

Jet Control - More effective results in utilising blowing jets may be achieved by designing a control system which changes the rate of flow as a function of angle of attack.

A control system can be devised to vary the rate of flow in order to keep low values of side force coefficients.

Effect of Reynolds Number and Mach Number Changes

At this stage of tests it is impossible to define the effects of Mach number on side forces.

Further tests are required in order to investigate the effects of both Mach number and Reynolds number on the lateral forces and moments of these slender configurations at high angles of attack with and without blowing.

REFERENCES

1. Pick, G.S.: Investigation of side forces on ogive cylinder bodies at high angles of attack in the M = 0.5 to 1.1 range, AIAA Paper No. 71-570, 1971.

2. Krouse, J.R.: Induced side forces on slender bodies at angles of attack and Mach numbers of 0.55-0.80, NSRDC Test. Rpt. May 1971.

3. Thomson, K.D., and Morrison, D.F.: The spacing position and strength of vortices in the wake of slender cylindrical bodies at large incidence, Weapons Research Establishment, Salisbury, South Australia, Tech. Rept. NSA 25, June 1969.

4. Lamont, P.J., and Hunt, B.L.: Pressure and force distribution on a sharp-nosed circular cylinder of large angles of inclination to a uniform subsonic stream, Journal of Fluid Mechanics, Vol. 76, pp. 519-559.

5. Lamont, P.J., and Hunt, B.L.: Prediction of aerodynamic out of plane forces on ogive-nosed circular cylinders, Journal of Spacecraft, Vol. 14, No. 1, January 1977, pp. 31-44.

6. Keener, E.R. and Chapman, G.T.: Onset aerodynamic side forces at zero sideslip on symmetric forebodies at high angles of attack, AIAA Paper No. 74-770, 1974.

7. Letko, W.: A low speed experimental study of directional characteristics of a sharp-nosed fueslage through a large angle of attack range at zero angle of sideslip, NACA TN 2911, March 1953.

8. Clark, W.H., Peoples, J.R. and Briggs, M.M.: Occurrence and inhibition of large yawing moments during high incidence flight of slender missile configurations, AIAA Paper No. 79-968, 1972.

APPENDIX A

Preliminary tests in the high subsonic and in the transonic regions

The tests were carried out in the transonic wind tunnel of the Aeronautical Research Center of the Technion, which has a cross section of 60 cm x 80 cm. The model is the pointed cone nose (Fig. 1). The investigation included experiments with and without jet injection at Mach numbers of 0.6 and 0.8, for angles of attack between 35° to 56°. The injection took place at station A (Fig. 1), at an angle of -30° and with a blowing coefficient of $C_\mu = 149.4x10^{-7}$ for M=0.6 and $C_\mu=84.07x10^{-7}$ for M=0.8.

Schlieren photographs were taken during the tests. At M = 0.6 the blowing had only little effect on the reduction of the side force coefficient (Fig. 10), although it reduced to some extent the yawing moment (Fig. 11). However, at M = 0.8 both side force and yawing moment were considerably reduced within the range of the angles of attack $35° < \alpha < 48°$ (Figs. 12, 13). The effectiveness of the blowing disappeared for angles of attack higher than 48°.

From Schlieren photographs (Fig. 14) it can be seen that a shock wave appeared near the shoulder of the body at M = 0.8. However, the flow picture with jet blowing (Fig. 14-b) is different from the flow without blowing (Fig. 14-a). The considerable reduction in side force and yawing moment at M = 0.8 encourages further investigation for the effect of jet blowing.

Effects of Reynolds number, influence of the rate of blowing and shock wave formation should be investigated at these and higher transonic Mach numbers.

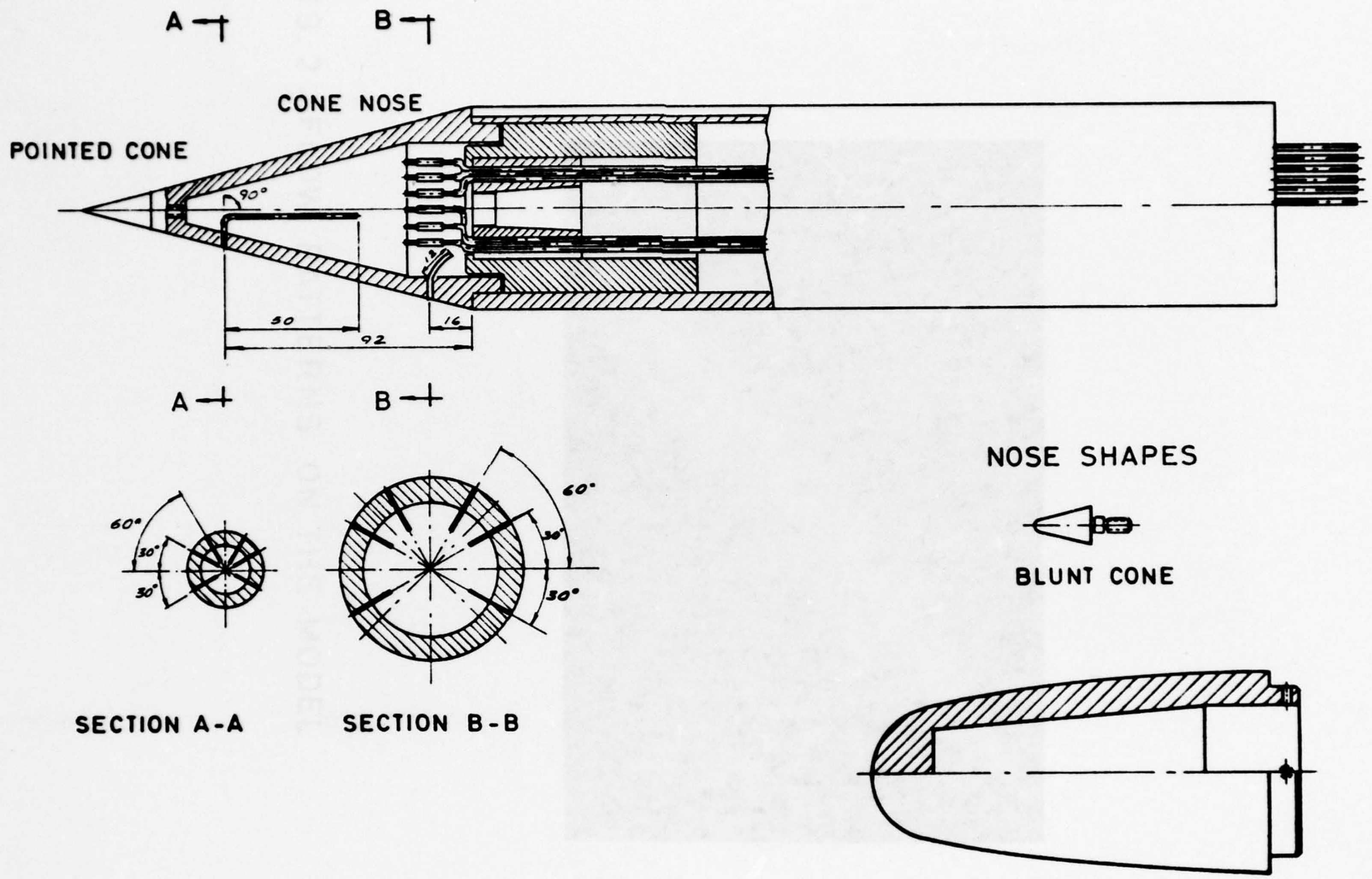


FIG.1-WIND TUNNEL MODEL

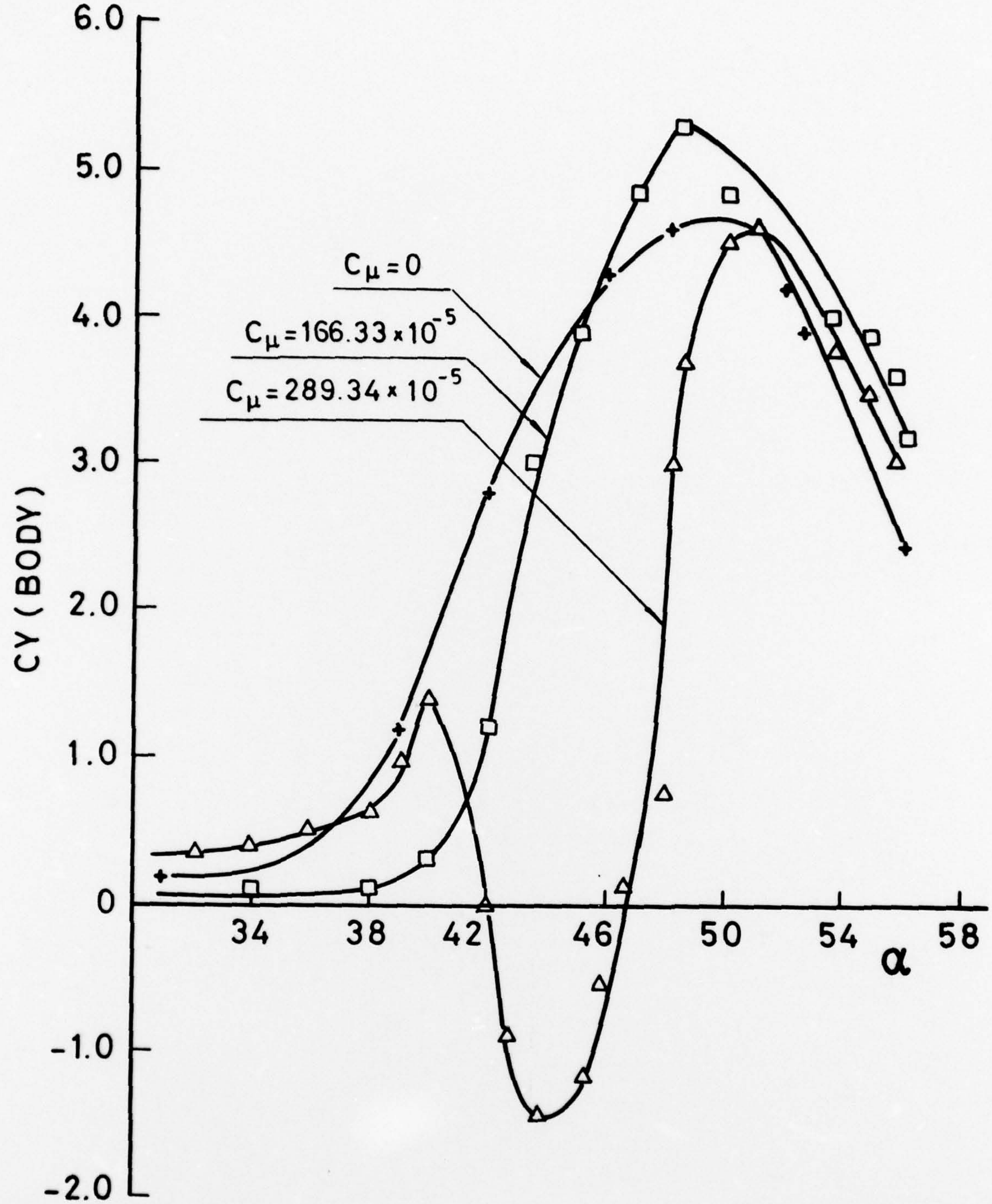


FIG. 3 - SIDE FORCE COEFFICIENT VERSUS ANGLE OF ATTACK FOR INIJECTION AT STA. I ANGLE +30° (POINTED CONE)

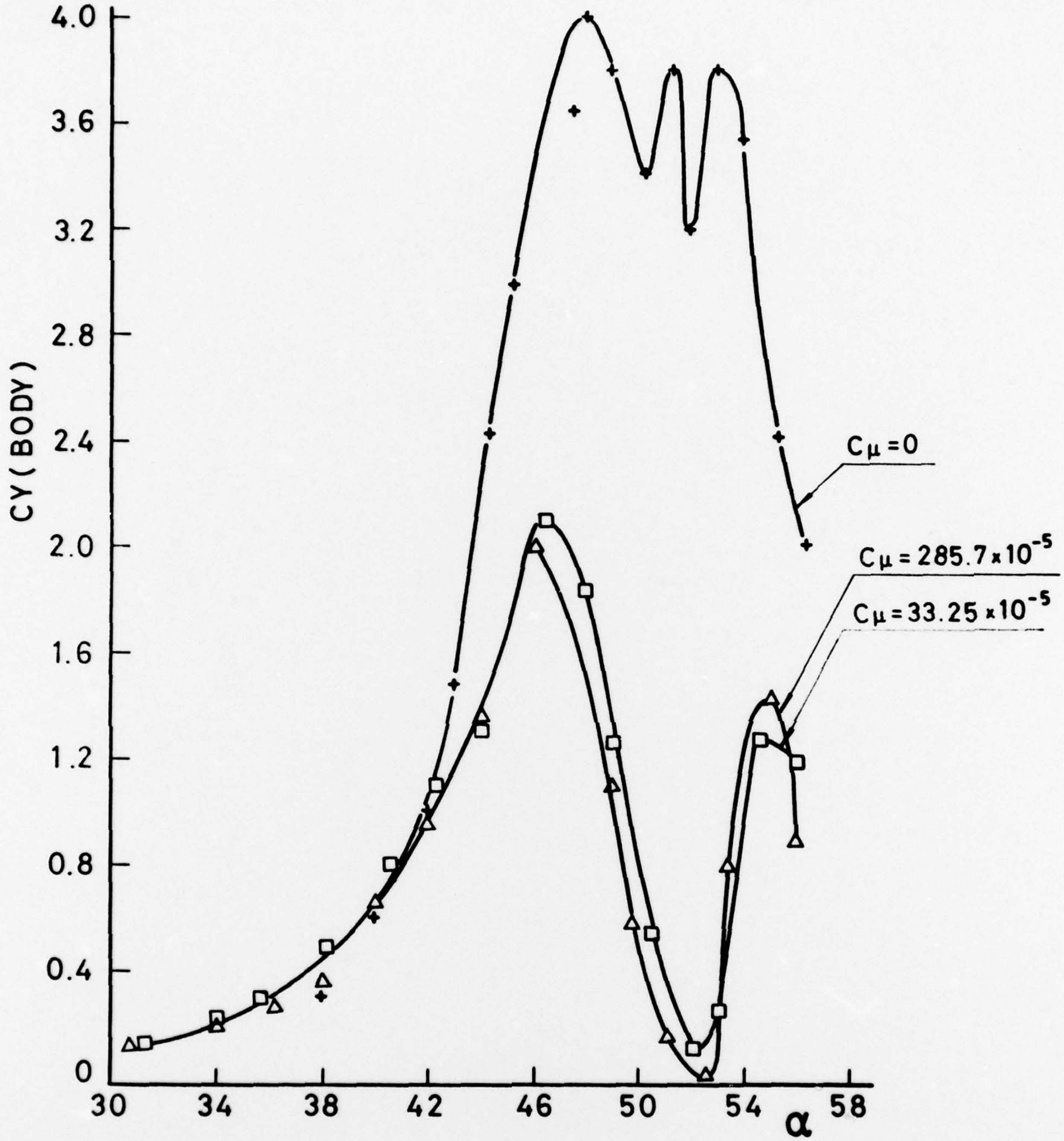


FIG. 4 - SIDE FORCE COEFFICIENT VERSUS ANGLE OF ATTACK FOR INJECTION AT STA. II ANGLE -30° (POINTED CONE, $V = 20 \frac{m}{sec}$)

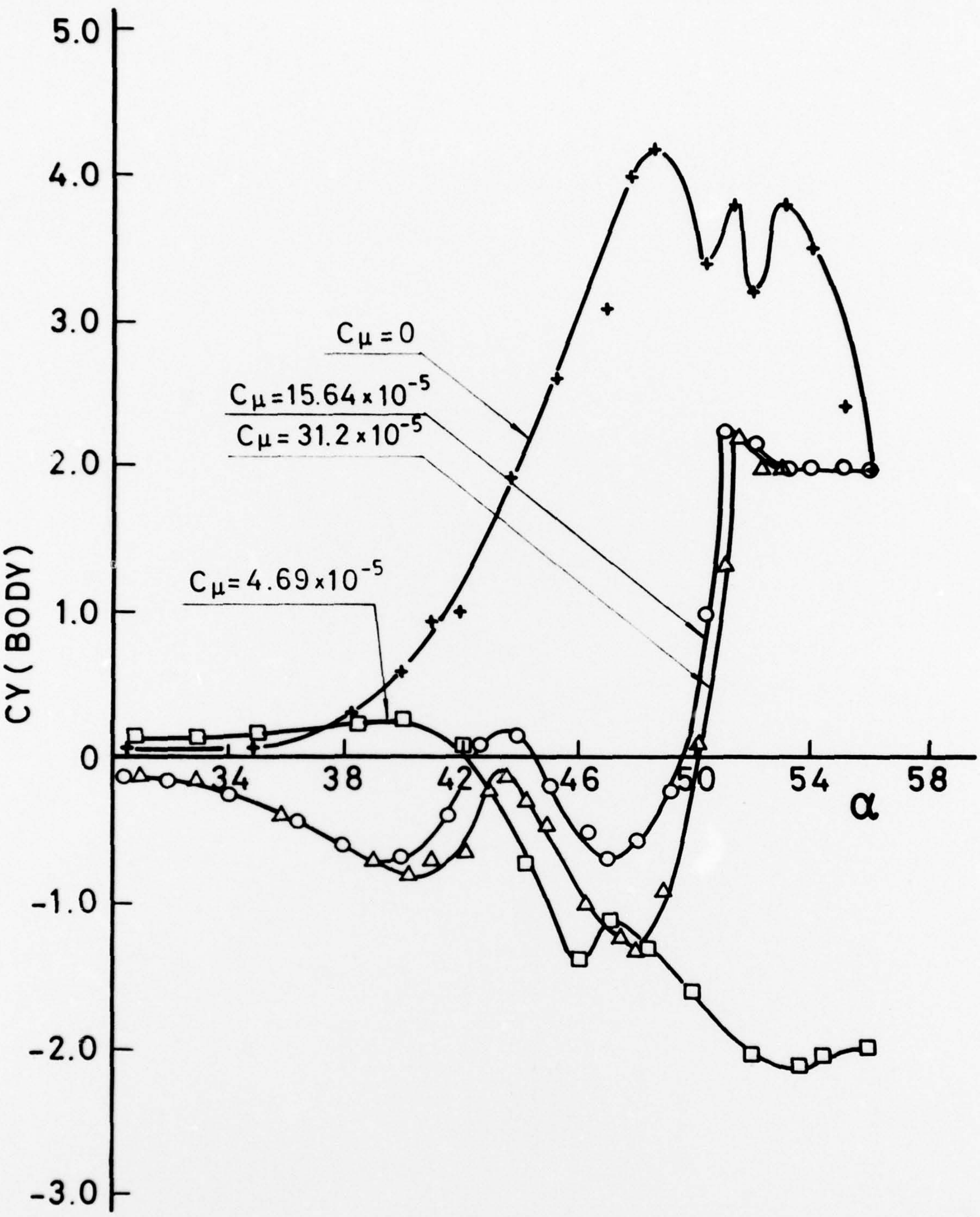


FIG. 5 - SIDE FORCE COEFFICIENT VERSUS ANGLE OF ATTACK FOR INJECTION AT STA. I ANGLE -30°
(POINTED CONE $V = 20 \frac{m}{sec}$)

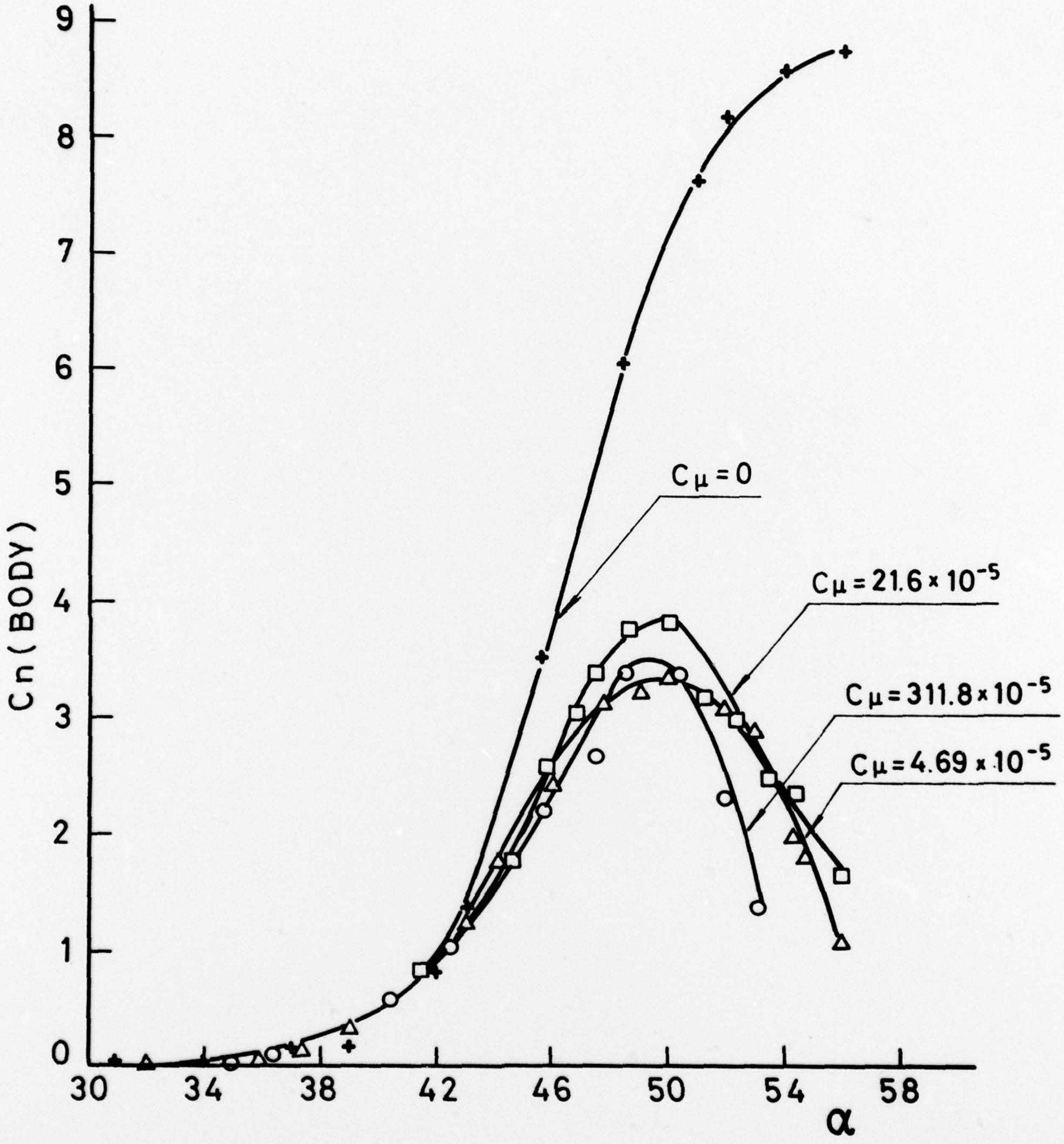


FIG.6 - YAWING MOMENT COEFFICIENT VERSUS ANGLE OF ATTACK FOR INJECTION AT STA. I ANGLE -30° (POINTED CONE, $V = 20\ \frac{m}{sec}$)

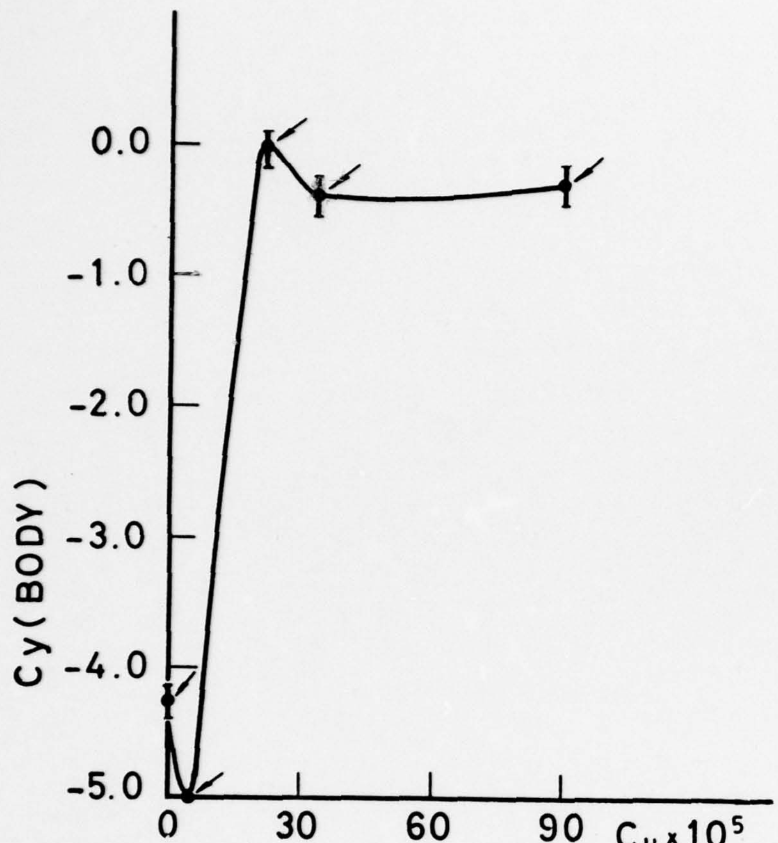


FIG. 7- CHANGE OF SIDE FORCE COEFFICIENT AT 45° ANGLE OF ATTACK FOR INJECTION AT STA. I ANGLE -30°, (POINTED CONE)

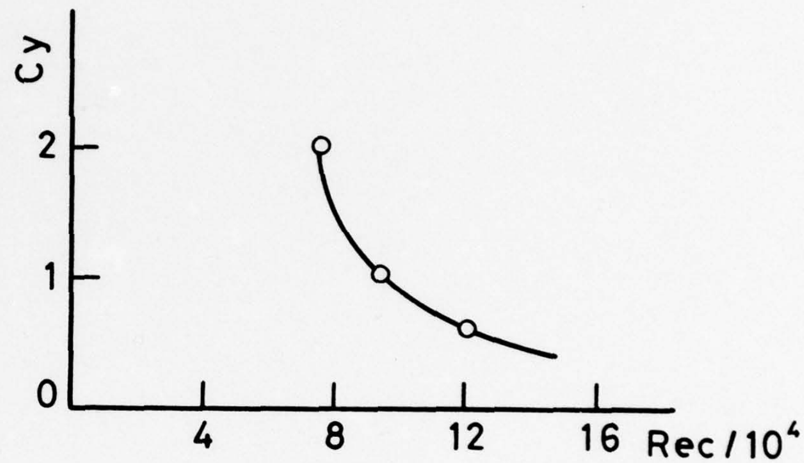


FIG. 8 - SIDE FORCE COEFFICIENT VERSUS CROSS FLOW REYNOLDS NUMBER AT $\alpha = 45°$ $C_\mu = 21.6 \times 10^{-5}$

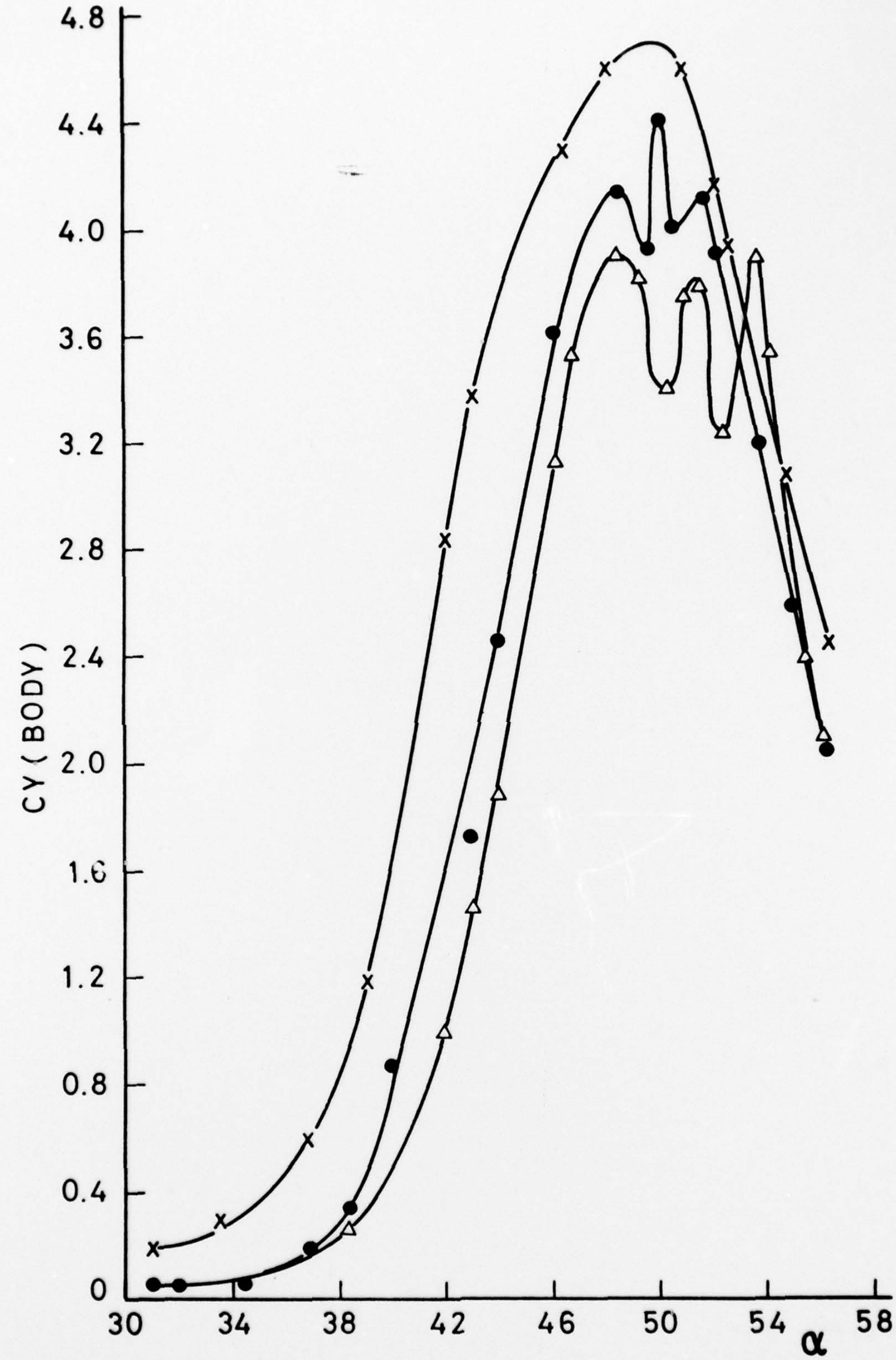


FIG. 9 - SIDE FORCE COEFFICIENT VERSUS ANGLE OF ATTACK (C_μ=0)

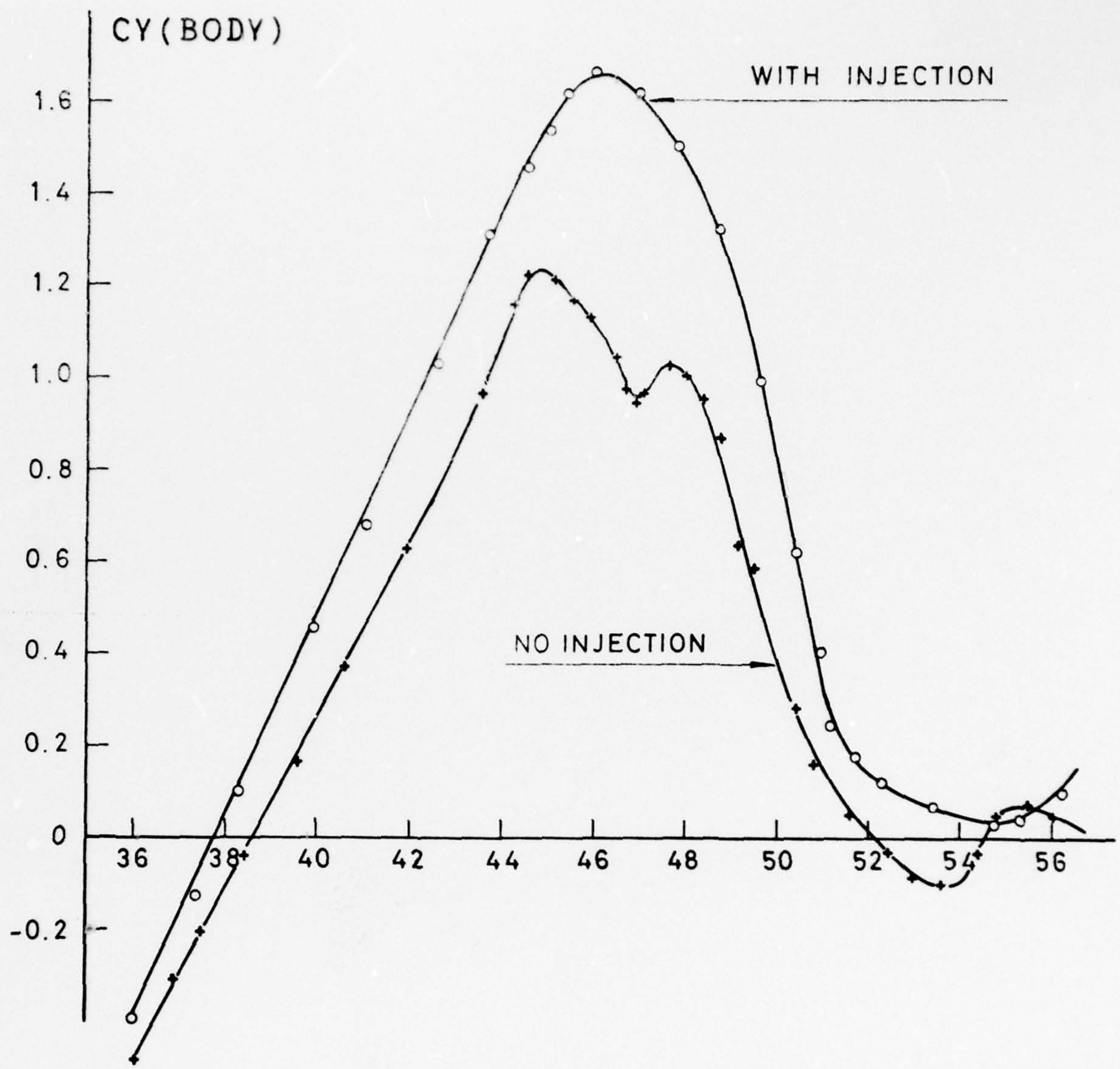


FIG. 10 - SIDE FORCE COEFFICIENT Vs. ANGLE OF ATTACK, AT 0.6 MACH NUMBER $C_\mu = 149.4 \times 10^{-7}$

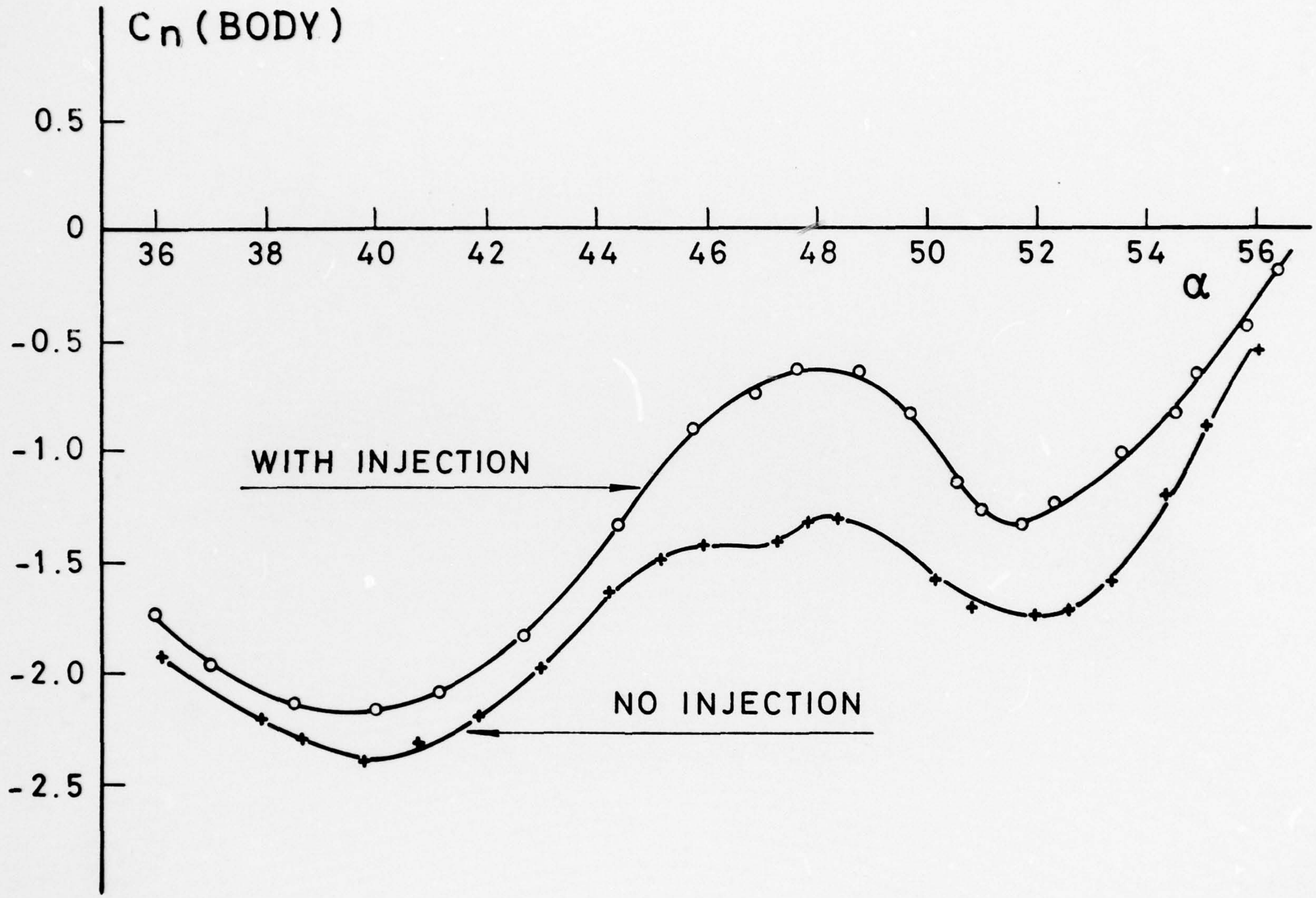


FIG. 11-YAWING MOMENT COEFFICIENT Vs. ANGLE OF ATTACK, AT 0.6 MACH NUMBER $C_\mu = 149.4 \times 10^{-7}$

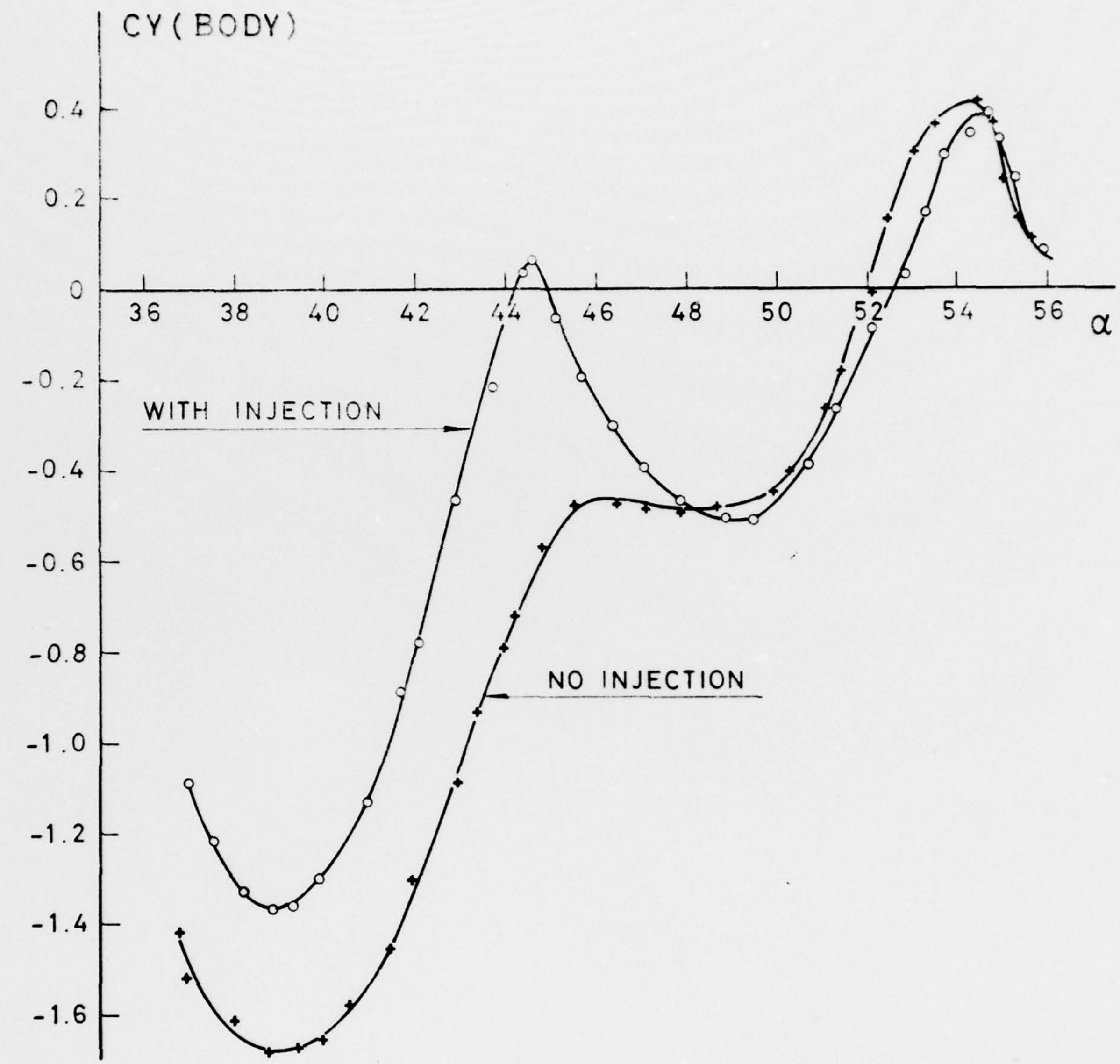


FIG. 12 - SIDE FORCE COEFFICIENT Vs. ANGLE OF ATTACK, AT 0.8 MACH NUMBER $C_\mu = 149.4 \times 10^{-7}$

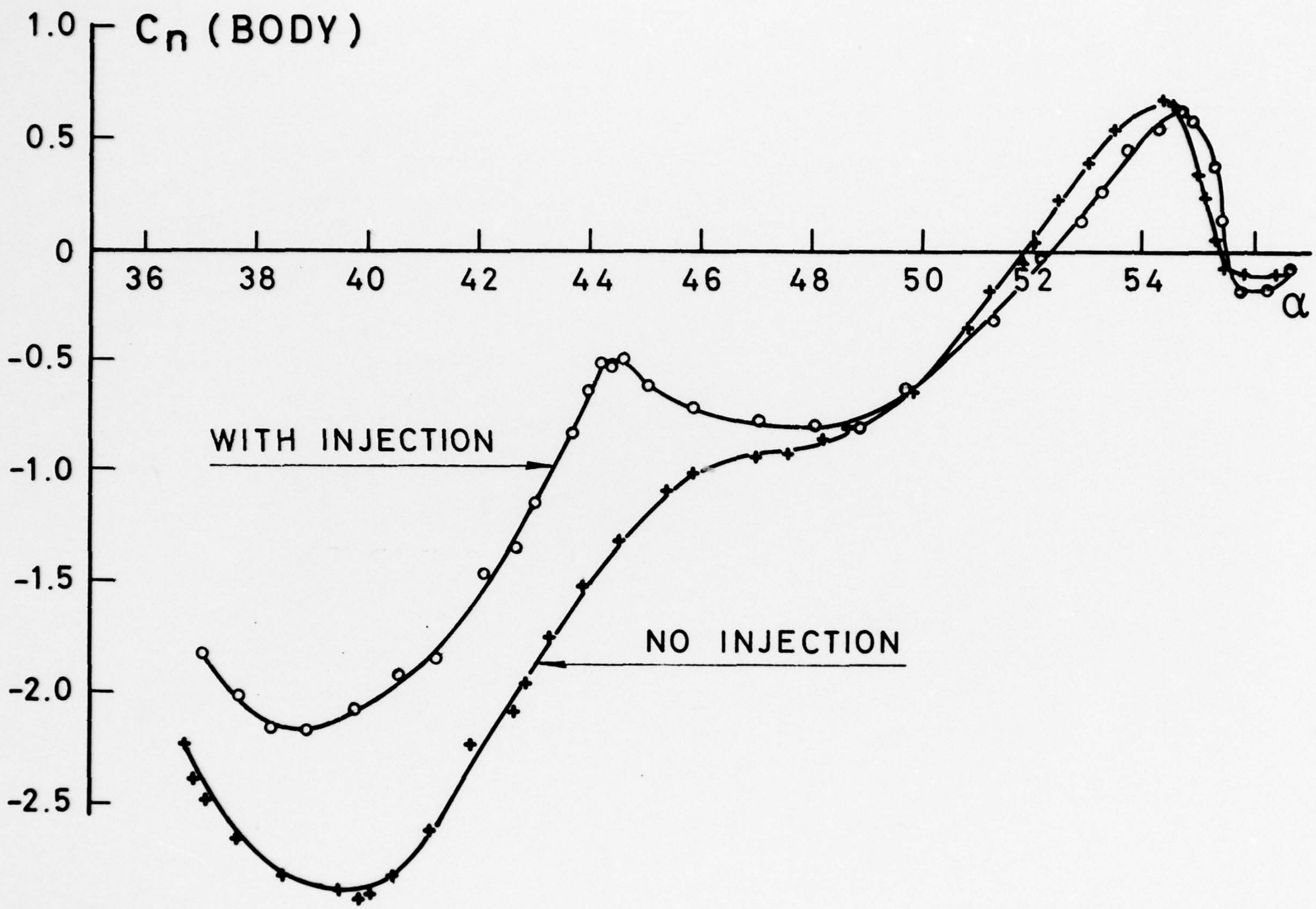
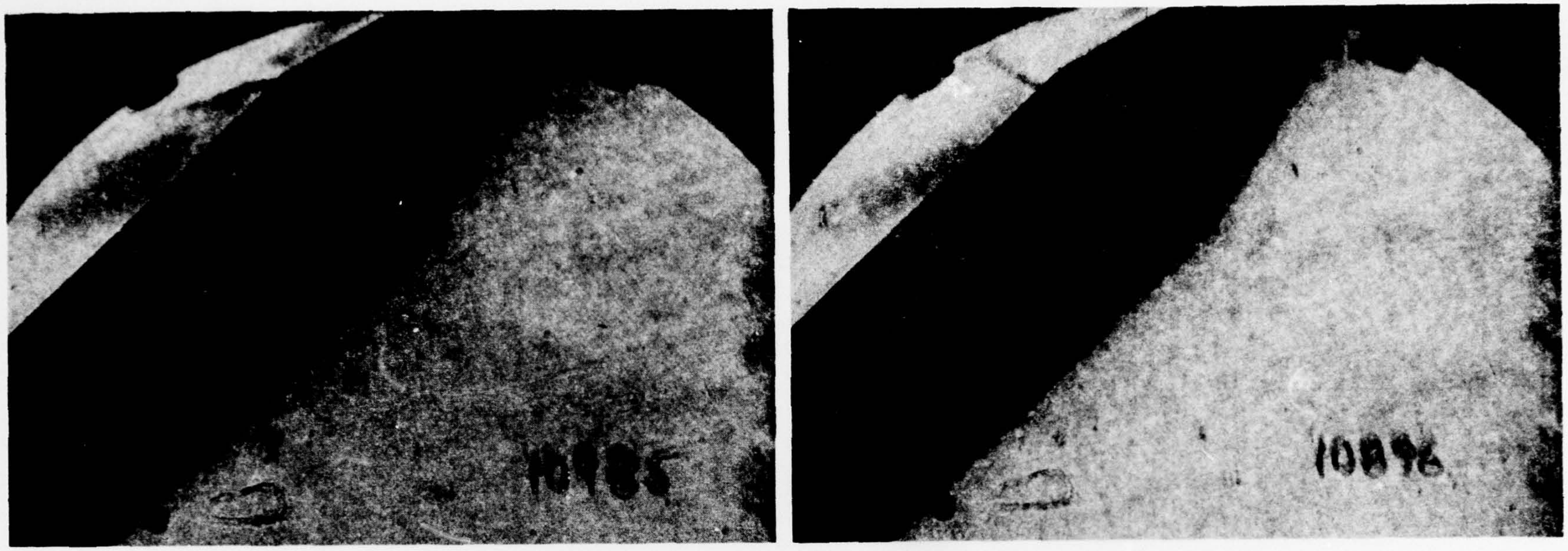


FIG. 13 - YAWING MOMENT COEFFICIENT Vs. ANGLE OF ATTACK, AT 0.8 MACH NUMBER $C_\mu = 84.1 \times 10^{-7}$



a
NO INJECTION

b
WITH INJECTION

FIG. 14 - SCHLIEREN PHOTOGRAPHS OF THE BODY AT 0.8 MACH NUMBER, $\alpha = 44°$